VEGETATION AND ENGINEERING STRUCTURES IN FLOOD AND EROSION CONTROL

By

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VEGETATION AND ENGINEERING STRUCTURES IN FLOOD AND EROSION CONTROL

Man's existence and economic well-being hinge upon his ability to live in harmony with the relentless forces of nature. Floods and soil erosion often are manifestations of a lack of harmony between man and his environment; this harmony must be reestablished if soil, water, vegetation resources, and man's culture itself are to be preserved. This paper discusses flood and erosion phenomena with special emphasis on their causes and control. It deals primarily with the Intermountain region of the western United States, for there the authors did most of their research and gained most of their experience with floods and erosion. However, the concepts and principles used in the analysis of flood and erosion problems and in the formulation of control programs in this area are basic to any program of erosion and flood control in which vegetation--forest or other--is to play an important part.

Throughout this discussion vegetation is emphasized as the most efficient natural means of maintaining or restoring the norm of watershed hydrology and soil stability where it is determined that mismanagement of the lands or inadequate protection has resulted in accelerated flood occurrence and soil erosion.

In reestablishing the hydrologic norm of a watershed, revegetation and land management alone are often not enough to do the job but must be supplemented by engineering structures. Such engineering work must be integrated with plans for reforestation and revegetation. The role that forests can play in controlling floods and erosion rests primarily on the well-established concept that a fundamental relation exists between plant cover, soil stability, and streamflow. An understanding of the interrelatedness of the plants, animals, soil mantle, and water on forest lands is essential to the development and application of successful control measures. All vegetation--even low-growing, herbaceous plants--plays an important role in the reception and disposition of precipitation which falls on the watershed lands. Neglect of these hydrologic aspects of forest and range management has brought about floods and accelerated erosion in many parts of the world. Recognition of the functions performed by the soil and vegetation will be essential to the application of forest and range management to the prevention and control of floods and erosion. Regulating streamflow and maintaining stability of the soils through management of vegetation is an old concept. This basic principle was enunciated more than 60 years ago by Dr. Thomas C. Chamberlin, geologist, at a historic meeting on conservation at the University of Chicago. He said,

"The key lies in due control of the water which falls on each acre. . .the highest crop value will usually be secured where the soil is made to absorb as much rainfall and snowfall as practical. . .this gives a minimum of wash to foul the streams, to spread over the bottomlands, to clog the reservoirs, to waste the water power, and to bar up the navigable rivers." Subsequent experience and research have shown the wisdom and soundness of this statement, and today the basis of modern forest and range conservation practices is the control of water where it falls as rain or snow.

VEGETATION EFFECTS

Vegetation exercises multifunctional effects in control of floods and erosion. Among these are: interception, transpiration, energy dissipation, soil stabilization, and enhancement of infiltration.

While the amount of precipitation intercepted may be relatively small, the interception process is of greatest significance in dissipation of the energy impact of raindrops and in diminution of the amount of water requiring disposal by hydrologic processes. Intense rainfall unleashes energy having a tremendous dispersion capability. Nichols and Gray (8) calculated that 2 inches of falling rain per acre would have 6 million foot-pounds of kinetic energy--sufficient to raise a 7-inch layer of soil to a height of 3 feet over this same acre. Live vegetation and plant litter protect the soil mantle against this dispersive force by dissipating this energy. They contribute further to soil stability by binding the soil into stable aggregates that resist transport by flowing water.

Transpiration by plants depletes the soil mantle of enormous quantities of water--as much as 20 inches or more per year. Growing-season draft on stored water creates moisture storage capacities of several inches per foot of soil each year. When vegetation is reduced, irrespective of cause, annual moisture depletion is reduced and maximum moisture storage capacity within the mantle is not developed. The consequence is the need for safe handling of more water.

Vegetation promotes infiltration and permeability by two means: the production of litter that is subsequently incorporated as humus, and the ramification of root systems, both of which increase porosity in the soil mantle. These properties remain high when the mantle is protected and percolating water remains clear. But intense rainfall on bare soil has an immediate effect of dispersing and suspending soil particles. As a result, sediment-laden water infiltrates slowly and suspended particles soon clog soil pores, and thereby reduce the final infiltration capacity and increase overland flow.

In addition to the functions of vegetation already mentioned, soil mantle development and potential sediment production are conditioned by plant cover (fig. 1). The horizontal axis indicates that in time soil development commences from bare rock. Disintegration and decomposition, acting under the protective influence of vegetation, may eventually produce a mature deep soil mantle. The vertical axis shows that erosion of parent material is low--that it keeps pace with the breakdown of rock in the absence of plant cover. As time passes, soil and plant cover development increase concomitantly and erosion decreases to a low geologic norm. The erosion potential is ever present and continues to increase steadily as illustrated; but so long as the soil is protected by vegetation, actual erosion continues low (6).

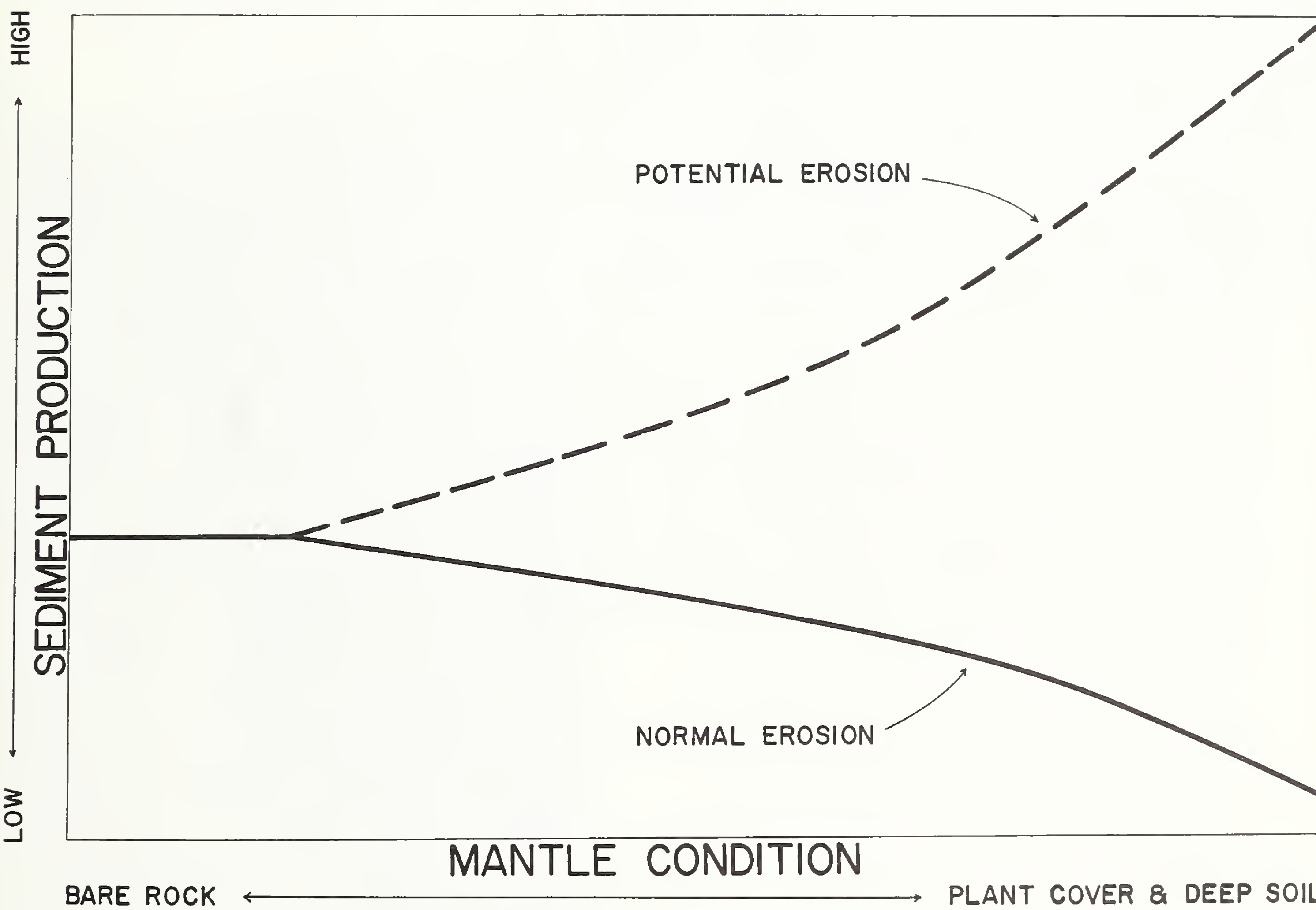


Figure 1.--The decrease in normal erosion and the increase in erosion potential that accompany development of a soil mantle under the protective influence of vegetation.

GEOLOGIC NORM

Also essential to the formulation of any flood and erosion control program through forestry and engineering is an understanding of the relation between current flooding and erosion to the geologic norm (1, 3). Watersheds with their soil and plant mantle, topography, and streamflow characteristics have been inherited from the geologic past. Their streams exhibit great natural variation in erosion and in flood behavior. Some streams are usually clear and flow with a relatively constant volume, but the regimen of other streams is marked by great variance in volume and time of flow and vast differences in sediment content. Each stream is the resultant of such normal factors and forces as climate, topography, geology, and the soil and plant mantle. All these factors and forces have operated through the ages to give rise to definite land forms, specific soils, vegetation complexes, and characteristic stream channels, streamflow, and sediment loads. Erosional processes at varying rates on the watershed slopes and in the channels are also part of the norm. We know, for example, that erosion is proceeding so slowly in some areas that soil is being formed and accumulated more rapidly than it is being removed. Streams from such areas carry only negligible loads of sediment. We know, too, that in other areas climatic and geologic conditions limit soil formation, plant growth, and fixing of the land surface. From these drainages runoff has always been rapid and erosion pronounced, giving rise to muddy and highly fluctuating streams. Moreover we know that between these extremes are all gradations of watershed conditions and sedimentation rates. Variations in sediment production in relation to watershed conditions are shown in figure 2.

Figure 2.--A. Morris Creek watershed, Utah, north-facing basin occupying 167 acres whose average slope is 48 percent with extreme gradients of more than 80 percent. Precipitation averages 30 inches annually which is completely infiltrated. Dense vegetation provides protection against erosion. Sediment production from this watershed is only 0.0025 acre-foot per square mile per year and represents a low geologic norm.

Figure 2.--B. Lost Creek watershed, Utah; 85 percent of area comprised of steep barren slopes. Active erosion and periodic flooding are characteristic of this basin giving it a high geologic norm. Small islands of soil protected by vegetation show no evidence of overland flow and erosion. Erosion removes soil material as rapidly as it forms from unvegetated slopes.

FLOODS

Seepage Flow Floods

Floods are a normal event in parts of all climatic and physiographic regions. In the humid southern and eastern portions of the United States, for example, as well as in the Pacific Northwest, watersheds are frequently subjected to copious rains or to deep snows and rains. In many parts of these regions, well vegetated soil mantles are capable of infiltrating virtually all of the rain and snowmelt with little or no overland flow. But even in the absence of overland flow, when copious rain and snowmelt water are available more precipitation may pass into the mantle than it can hold; this causes large volumes to drain rapidly from the soil into channels and thus create flood discharges.

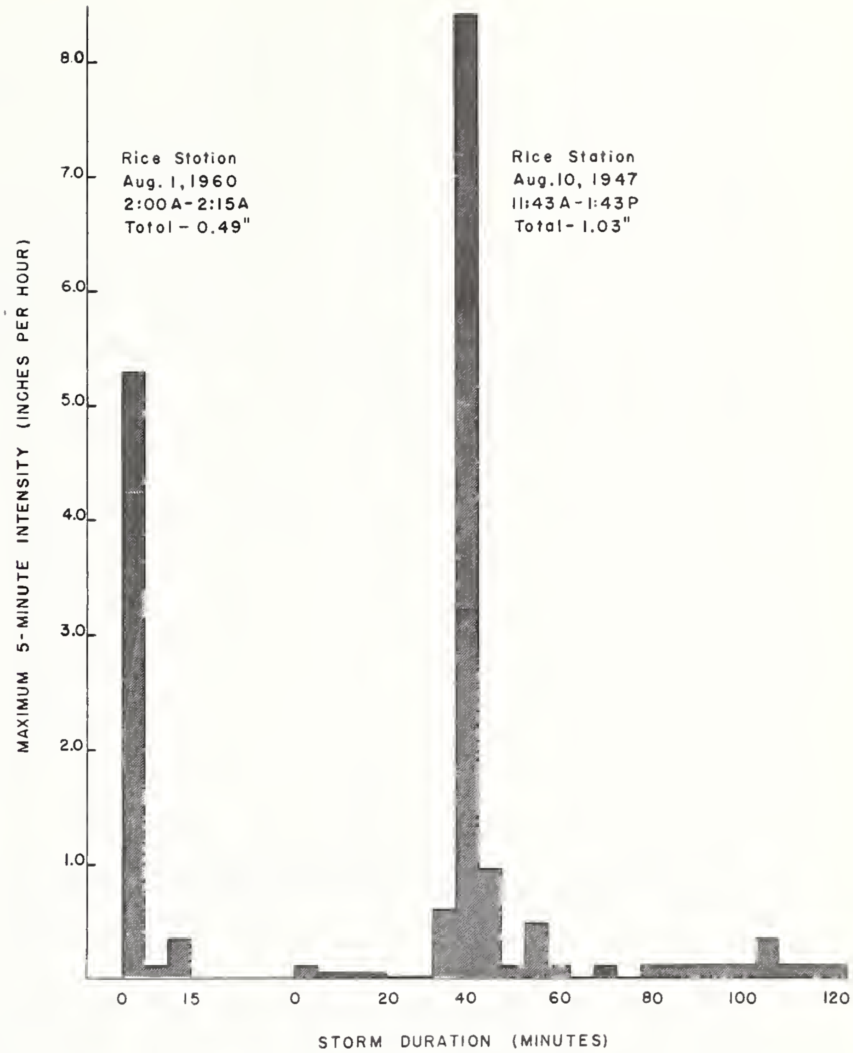
This phenomenon was strikingly illustrated by the Columbia River flood in the spring of 1948 (11). In this flood, water came principally from melted snow. Exceptionally heavy rains in the fall of 1947 largely filled the storage available in the watershed mantle. Unusually deep snow then accumulated on the Columbia River watershed during the winter, and subnormal temperatures in May delayed spring melting. Rains added more water to the snowpack and ripened it for melting. This situation was followed by uncommonly warm temperatures which released from 1 to 4 inches of water from the snowpack per day for several days over extensive areas. Release of this large volume of water to a mantle that was already saturated made a great flood inevitable. Other floods can be expected whenever similar climatic conditions recur.

Overland Flow Floods

Another kind of flood, whose characteristics contrast markedly with the seepage flow flood just described, occurs in the semiarid regions. Much of the Western United States, for example, is subject to torrential summer storms. Though these are usually of short duration and of limited extent, the rains fall at high rates, with great impact (fig. 3). Rain from this type of storm is a powerful eroding agent, especially on areas where the soil surface is exposed and slopes are steep (5).

In those parts of the West where the plant cover is sparse or nonexistent on steep slopes and where the soils are shallow or absent, violent debris-laden floods commonly follow torrential rains. On the other hand there are extensive areas, particularly in high mountains and plateaus on which has developed a plant and soil mantle capable of absorbing virtually all torrential rainfall. The normal incidence of flooding on these areas is

Figure 3.--Two high intensity storms that occurred on the Davis County Experimental Watershed, Utah. The brief 1960 storm reached the maximum intensity during the first 5-minute period. The 1947 storm lasted much longer. Its maximum intensity occurred 40 minutes after rain commenced.



low, and the geologic normal rate of erosion on watershed slopes is so slow in many places that the loss of soil is imperceptible. The consequence of disturbing the plant cover and soil mantle on these watersheds may be spectacular and catastrophic. Such disturbances, even when confined to a small portion of the watershed, can result in discharges greatly exceeding the normal and are accompanied by tremendous acceleration of erosion and sedimentation. Floods resulting from these torrential storms, whether originating on naturally unstable areas or on slopes whose plant cover has been impaired, have their origin in overland flow (fig. 4).

Overland flow is generally destructive runoff. It can occur whether the mantle is wet or dry, and starts whenever rain falls or snow melts at a rate faster than the water can infiltrate into the ground. Because this water flows over the land surface, it is capable of eroding the soil and gathering quickly into channels to produce discharges of great violence. Peak flow discharges of this type of runoff are known to exceed those from seepage flow by several hundredfold (fig. 4).

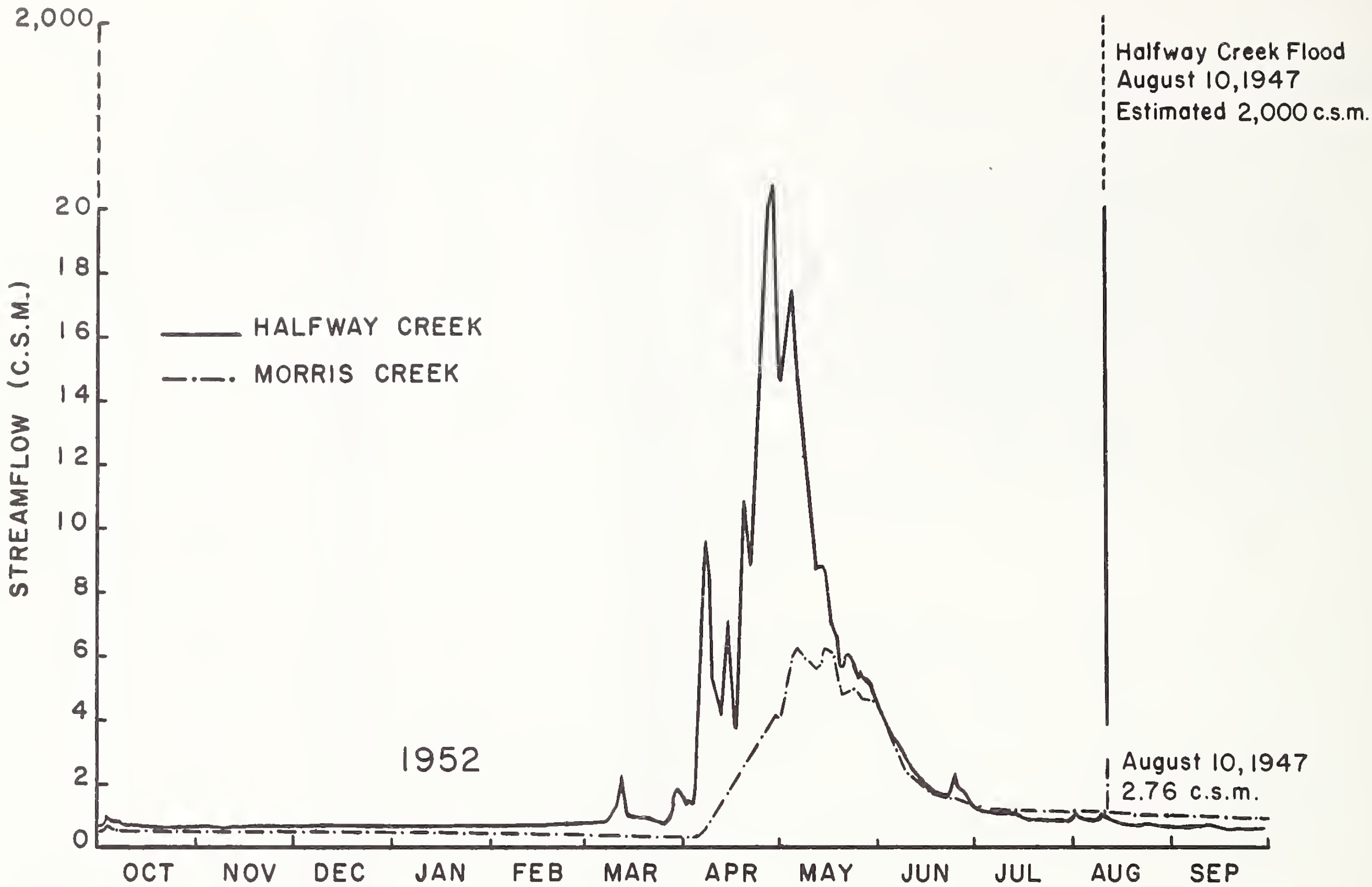


Figure 4.--Daily hydrograph for 1952 of Halfway and Morris Creeks. Peak discharges of 23 and 6 c.s.m. from the respective watersheds resulted from slow melting and complete infiltration of snowmelt water derived from a record snowpack containing 43 inches of water. Superimposed on this hydrograph are the peak discharges of each watershed following a high intensity storm on August 10, 1947, that produced only 0.79 inch of rain, but whose maximum 5-minute intensity was 4.92 inches per hour. The flood peak from sparsely vegetated Halfway Creek watershed exceeded 2,000 c.s.m. while the densely vegetated Morris Creek peaked at less than 3 c.s.m.

Whether runoff occurs as seepage flow or overland flow hinges primarily on the infiltration capacity of each watershed site. Many tests show much natural variation in the capacity of sites to infiltrate water due primarily to differences in structure and porosity of soils, as influenced particularly by the kind and amount of plant and litter cover. Also, experiments have shown that the infiltration capacity of a site can be materially decreased by reducing the density of the plant and litter cover on the surface of the ground and by trampling and compacting the soil. It is not unusual, for example, for sites having an undisturbed soil and a natural cover of plants and litter to absorb rainfall at rates in excess of 6 inches per hour, and for the same sites to absorb water at only 2 inches per hour or less after the plant and litter cover has been removed or drastically reduced. Such reductions of the plant cover can also change the rates of soil loss from nil or negligible amounts to many tons per acre per storm. Thus, erosion of soil is accelerated because precipitation that formerly entered the soil becomes overland flow.

FLOOD CONTROL

The foregoing discussion of the principles of watershed hydrology, which emphasized the role of vegetation in the reception and disposition of precipitation, was intended to explain the basis for flood and erosion control through forest and range management. A successful control program requires an understanding of the geologic norm of erosion and flooding in any drainage for which control measures are being considered. This is important because it defines the degree of control that can reasonably be obtained; furthermore, it largely dictates the system of control that should be applied. Knowing the source and cause or causes of flood runoff is also necessary in the control program. Flood control, as considered in this paper, has as its underlying principle the application of land treatments and watershed management practices that will either maintain or restore to an acceptable level the hydrologic characteristics of a drainage, including timing, peak, and volume of discharges, rates of soil erosion, and channel stability. To accomplish these objectives, such engineering structures as gully dams, channel stabilization structures, contour trenches, water bars, spreaders, and debris basins, must often necessarily be integrated with land treatment phases of flood control.

Large dams constitute the major feature of flood and sediment control programs in river basin planning in the United States. Their place in flood control is not discussed here. Suffice it to say that large dams capable of controlling floods on major rivers and of retaining sediment in the reservoirs they create cannot keep soils in place on the slopes or prevent ripping and scouring of tributary channels; nor can they prevent

reservoir destruction by the sediment resulting from accelerated erosion on the watershed slopes and in channels. Conflicting arguments between upstream land treatment programs and the big dam programs have no real merit. Both have their place and in most instances their construction and use should be coordinated in a basinwide control program. However, in river basin plans the watershed treatment program too often has been neglected. While dams and other downstream water projects reach completion, watershed treatments too often fail to materialize, fall short of full accomplishment, or are completely ignored.

Maintenance and Restoration of Watersheds

Two big problems of flood and erosion control face foresters in America. One is that of maintaining satisfactory watershed conditions on the forest and rangelands whose resources are to be utilized through timber harvesting and grazing of livestock. A second problem is that of restoring satisfactory water control on those areas that have suffered deterioration from unwise use and fires.

Maintenance of Normal Processes

Water that produced the Columbia River flood in 1948 was primarily the product of seepage flow from forested watersheds (11). Generally speaking, overland flow did not occur and consequently little or no erosion took place on the slopes. However, drainage channels leading from the steep, snow-packed watershed lands were severely scoured, even to bedrock in many places, by the large volumes of water that reached them as rapid seepage from a saturated mantle. Locally these channels overflowed their banks and caused considerable flood damage. It seems reasonable to assume that the best way to maintain optimum water disposal conditions in such a forested area as this would be to provide and maintain a complete forest cover. This would provide the greatest protection to the soil, assure infiltration of the rain and snowmelt, and effect maximum disposition of a significant portion of precipitation through interception and transpiration. Achievement of this goal, however, would deny the country the use of the timber resource, and would result in an economic loss that could not be justified. In view of the need for the multiple resources of these lands a system of timber harvesting that would provide for rotation and geographic placement of cutting units to reduce deleterious effects of timber harvesting on water yield and quality must be provided. Road construction--currently the most damaging disturbance on forested watersheds--must be done in such manner that the increased runoff from them will not cause accelerated erosion on the roads themselves or on the slopes below. Much

needs to be learned through research about proper road location and construction standards on critical watersheds. However, much is already known that could be better applied to greater advantage.

Fire protection is essential to maintenance of normal plant cover conditions and to rehabilitation of deteriorated areas. Observations during the floods in 1948 revealed that snowpacks on burned areas melted several days, and on some sites more than a week earlier than on forested slopes, although more snow probably accumulated on the burned areas than on the forested areas because of negligible interception. Irrespective of the means by which vegetation is destroyed, the task of properly disposing of larger volumes of water is increased. For example, measurements of the water available for streamflow from clear-cut plots of lodgepole pine compared to uncut areas in the Rocky Mountains indicated an increase of 30 percent or more (9).

Although maximum production and use of watershed resources, consistent with the limitations imposed by flood and erosion control requirements, are desirable, there are some areas in many watersheds in the West that should be reserved for certain uses and even some perhaps should be reserved from all uses. We must yet determine how to harvest timber or graze livestock safely without seriously upsetting the hydrologic balance on many areas because of the steepness of slope or some unusual soil characteristic. In the ponderosa pine forests of southern Idaho, many forested slopes should not be cut because of the failures that have been experienced in obtaining adequate reproduction. This situation is most prevalent on shallow soils, generally on south aspects, and until more exact information is obtained about how to achieve satisfactory regeneration of the forest, flood and erosion control requirements dictate that timber should not be removed from areas where soil is less than 18 inches deep.

Rehabilitation of Damaged Watersheds

Proper rehabilitation of our damaged forest and rangelands is an enormous and expensive job. On watersheds subject to wet-mantle floods, it will consist primarily of reforesting those areas that are understocked, or that have lost their timber cover because of repeated fires. Roads now in unsatisfactory condition will have to be improved. Check dams to arrest channel cutting and revetments to protect rapidly eroding banks may be required. Soil disturbance due to logging that results in a concentration of overland flow and consequent erosion must be stabilized by revegetation and mechanical structures, if required.

Watershed rehabilitation can prevent damage from seepage-flow floods in certain situations. For example, the Truckee River flood in 1955 seriously damaged the city of Reno, Nevada.[3/] Hydrologic analysis showed that if the peak discharge could have been decreased by about 2 inches of flow from the flood water source areas, damage would have been negligible or at least greatly reduced. A critical examination of the watersheds contributing to this flood showed that the forests had been greatly decimated by fires and uncontrolled logging and that most of the duff and litter normally developed on a forest floor and the organic matter in the top layers of the soil had been destroyed. It was concluded that interception and transpiration of precipitation and storage of water in the litter and duff under a normal forest condition would have reduced the discharge peak from the flood-source areas to a degree sufficient to have prevented the damage caused by the 1955 Truckee River flood.

Flood Control on the Wasatch Front, Utah

Devastating floods and erosion from torrential summer storms have occurred in many widely separated areas of the Western United States; some have threatened the very existence of communities situated at the mouths of canyons. Some of the most spectacular manifestations of these torrential flows, characterized as mud-rock floods, have occurred along the west face of the Wasatch Mountains in northern Utah (1, 4). Six adjacent watersheds ranging in size from 1,200 to 6,000 acres in the Farmington-Centerville section produced such typical floods in recent years.

Geomorphological investigations were fruitful in developing the flood history of these watersheds (1, 4). The Pleistocene Lake Bonneville, which once occupied the valley to the west of the mountains more than 10,000 years ago, left deltas with distinct profiles at the mouths of canyons, terraces both wave-cut and wave-built across the land features at the base of the mountains, and bars and spits athwart the drainages. These lake-formed features made it possible to evaluate recent erosion in terms of normal for the post-Bonneville epoch and thus establish the degradational and aggradational history of these tributary streams. Studies revealed that the recent floods occurring since 1900 cut to extraordinary

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3/ Croft, A. R. 1956. Memorandum report, M - FLOOD CONTROL, Floods, Truckee, December 1955. U.S. Forest Service, Region 4, 2 pp. (typed).

new depths into the previously undisturbed silts and sands of the delta deposits--depths as great as had been eroded during all of the previous post-Bonneville period. These floods also deposited quantities of boulders and other sediments far in excess of the previous post-Bonneville rate of deposition, on the black nonbouldery soils in front of the canyons formed from the deposits of the old lake. These rocky deposits indicate the new floods to be unprecedented in post-Bonneville history.

By following the freshly scoured channels up from the valley, the sources of these floods were found to be areas varying from less than one acre to a few acres in extent in the headwaters at elevations of 7,500 to 9,000 feet; on these flood-source areas the plant and litter mantle had been drastically reduced by very heavy overgrazing and to some extent by fire. That these areas were the source of the flood runoff was evidenced by an efficient system of gullies freshly cut in the soil mantle. In the aggregate these deteriorated and gullied flood-source areas covered less than 10 percent of the mountainous catchments (fig. 5).

Adjacent to and intermingled with these flood sources were well-vegetated areas on which there was no evidence of overland flow or soil loss; litter was undisturbed and there were no rill marks or freshly incised gullies. Examinations of the soil mantle immediately following flood-producing storms support the conclusion that, unquestionably, these areas received as much rainfall as the gullied, flood-producing areas but were able to absorb and store it.

Validity of the observations identifying watershed areas from which flood waters came was subsequently verified by measuring rainfall runoff and erosion from designated flood and nonflood source areas (table 1). During several of the heaviest summer rainstorms ever experienced in northern Utah, the sparsely vegetated and denuded areas yielded as much as 61 percent of the rainfall as overland flow whereas overland flow from the nonflood source plots was less than 1 percent. At the same time, the flood source areas yielded as much as 215 cubic feet of soil per acre during individual storms while no erosion occurred on the nonflood-source areas.

Infiltrometer tests on vegetated and partially denuded areas in the flood-producing catchments illustrated repeatedly the part that cover impairment played in causing floods. The accompanying illustration (fig. 6) shows how efficiently ground cover controlled runoff and erosion under the impact of a simulated rainfall of 2.44 inches per hour on subalpine rangeland. Where adequate ground cover exists, it holds overland flow to a low acceptable level and keeps erosion at a minimum.

Figure 5.--Moderate slopes in the head of Ford Canyon, with small areas denuded and gullied. Note how gullies start at the upper edge of bare spots.

Recognizing and understanding these complex relationships aided in the design of a watershed program to reestablish the plant cover and to stabilize the soil on deteriorated portions of the flood-producing watersheds between Centerville and Farmington in the Davis County, Utah area (2, 4). The two main features of this program were: (1) closure of the area to grazing and intensification of fire control to prevent further depletion of the plant cover; and (2) construction of contour trenches and artificial reseeding on about 1,300 acres of the flood-source areas. Contour trenches were installed to break up the gully system, to store and facilitate infiltration of precipitation where it fell and thus prevent overland flow and erosion, and create favorable conditions for revegetation. Artificial reseeding was done to hasten the establishment of vegetative cover on those areas incapable of rapid natural recovery.

This program of rehabilitation in the Davis County Experimental Watershed has been tested by numerous summer storms, and no floods

have developed from the treated areas. The nonflooding behavior of these rehabilitated watersheds has been evaluated (5) and is particularly significant when one considers that during two storms greater rainfall rates were attained than had ever been recorded in the State of Utah. During a rainfall of 1.14 inches on July 10, 1936, a rate of 5.04 inches per hour for a 5-minute period was registered. On the evening of August 19, 1945, when 1.09 inches of rain fell, rates at several of the recording gages exceeded 6.00 inches per hour for a 5-minute period, and at one a rate of 6.80 inches per hour was registered. On August 10, 1947, another storm produced a maximum 5-minute intensity rate of 8.4 inches per hour.

The storm on July 10, 1936 produced no floods from the treated watersheds, but the same rainfall caused mud-rock floods in four drainages within the area that had not been treated. Rehabilitated watersheds again on August 19, 1945, when subjected to the unusually high rainfall rate of 6.00 inches per hour, disposed of the precipitation without erosion or runoff of flood proportions.

Centerville Canyon, one of the experimental watersheds which has not deteriorated and which has never produced a mud flow in recent times, received the same amount and intensity of rainfall as the adjacent fully treated Parrish Canyon. There was no evidence of surface runoff reaching

Table 1.--Summer storm rainfall and resultant overland flow and soil losses from Parrish Plots, Davis County Experimental Watershed, Utah.

Storm dates	Total rainfall	Nonflood-source area		Flood-source area		Artificially denuded	
		Overland flow	Soil eroded	Overland flow	Soil eroded	Overland flow	Soil eroded
	Inches	Percent	Cu.Ft./A.	Percent	Cu.Ft./A.	Percent	Cu.Ft./A.
7/10/36	1.14	0.7	0	42.8	181.5	-	-
7/16/36	0.89	0.4	0	43.4	153.6	-	-
7/28/36	1.21	0.2	0	33.0	83.2	-	-
8/18-20/45	3.09	0.5	0	24.3	92.8	-	-
7/10/50	0.70	0.9	0	12.6	Tr.	61.3	215.3
8/19/51	1.15	0.6	0	8.4	Tr.	46.6	186.2
8/4/54	1.17	0.4	0	3.8	Tr.	31.3	91.3
8/19-20/59	0.98	0.6	0	2.3	Tr.	43.7	98.4

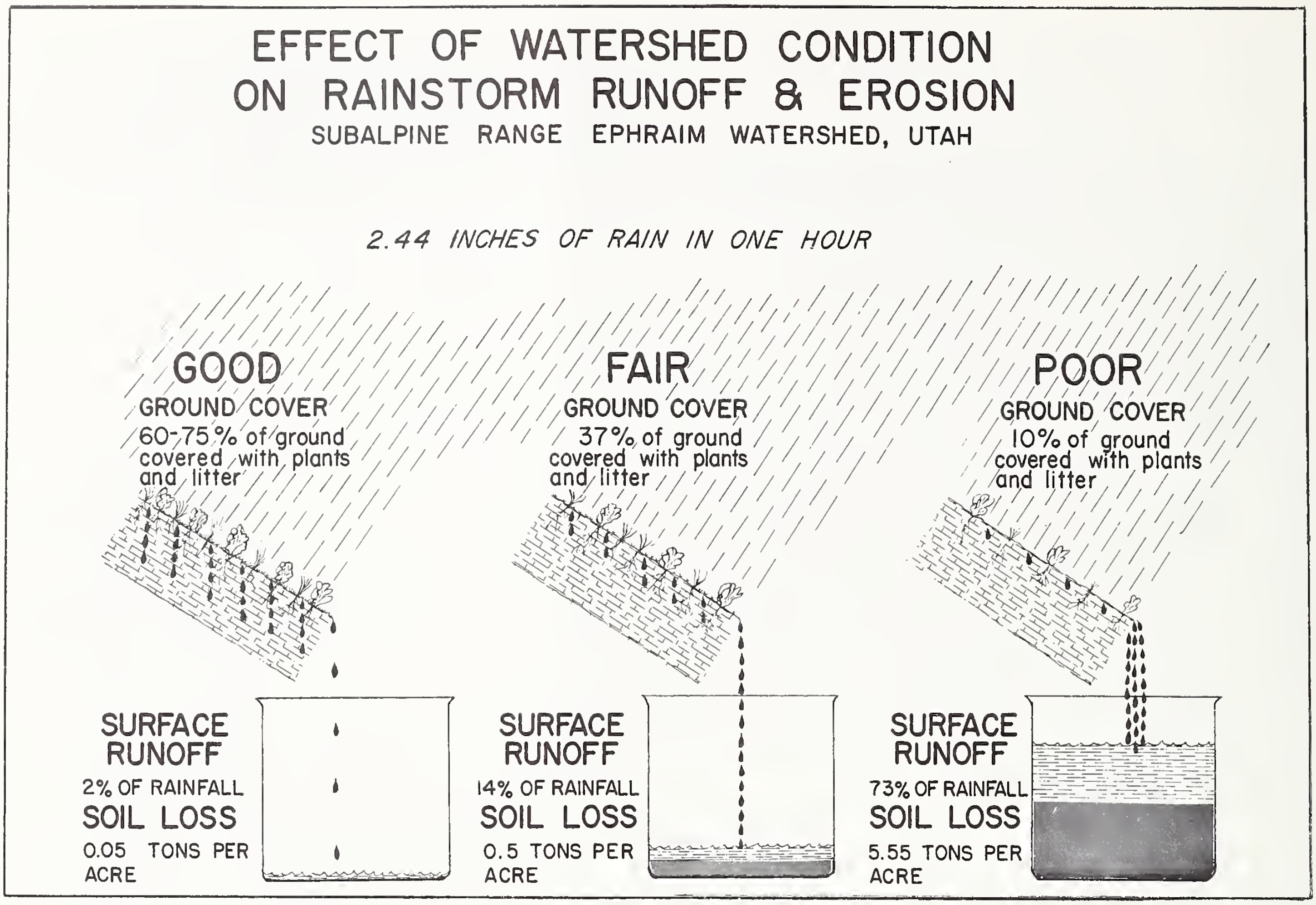

Figure 6.--Effects of various densities of ground cover in controlling overland flow and soil erosion.

the stream channels in either of these basins during the record-breaking rains on July 10, 1936, and August 19, 1945. The only storm flow from these basins was that which came from precipitation that fell in the stream channels.

In contrast, on the same evening of August 19, 1945, a mud-rock flood issued from a deteriorated watershed immediately adjacent to the treated experimental watersheds.

Behavior of these improved watersheds during the period 1936 to date marks a significant and radical departure from their behavior when they were in deteriorated condition in 1923 and 1930. This change from one of violent flooding and very high debris content to one of virtually regulated flow and low sediment load is in keeping with the basic principles of watershed management that have developed from wide experience and experimentation.

Integration of Structures Into Flood Control Programs

On sites whose productive potential is not seriously impaired, protection and properly regulated use usually restore vegetation to a level that will provide adequate flood and erosion control. Where desirable plants have been destroyed and natural revegetation is likely to be too slow, planting or reseeding is necessary. Where watershed slopes and channels have eroded to an extent that precludes natural recovery or artificial re-establishment of vegetation, supplementary mechanical measures are required.

Each of the several structures referred to above has a specific complementary value to watershed rehabilitation if applied with proper discretion and due cognizance of its capabilities. The place of dams in river basin flood control programs has been acknowledged, for it is recognized that they can materially help contain and lessen damage that results from widespread seepage-flow floods.

In the matter of overland flow floods, both engineering works and watershed management can contribute mutually to successful flood control and erosion abatement. As a matter of fact, a real need exists for applying structures directly on the land to help restore immediate control of water in place. These include debris basins, contour trenches, gully dams, concrete channel cribbing, revetments, water bars, and diversion features.

Debris basins and retaining walls have their greatest value downstream on small drainages where flood flows are not amenable to control by slope treatment alone. Debris basins spread the flood flow, reduce its velocity, and thereby cause the settling of suspended debris and sediment. Essential components are the cross dike, spillway, lateral dikes, stilling basin, and drift dams. Theoretically, debris basins contain the flows until sediment is deposited; then water relieved of its heavier sediment is discharged harmlessly through the spillway.

Mud-rock floods, common to the Western United States, often fail to conform to an established hydrodynamic pattern, and may bypass or not be contained by the basin. Those floods that do conform hasten the reduction of the useful life of the basins by filling them with sediment. A practical limit restricts the height of walls of a basin. When this is exceeded and the basin capacity is filled, the situation may then be worse than had no debris basin been built.

The principle of contour terracing as a soil conservation measure is very old, yet the application of contour trenches on forest and rangelands for preventing devastating floods and soil erosion is relatively new. The object in contour trenching depleted slopes is to assist in reestablishing the control of water by the site. Trenching does this by retaining the water on the land where it falls, thereby preventing overland flow and erosion; also by creating favorable soil moisture conditions that hasten the restoration of plant cover that otherwise might develop too slowly to provide control.

The contour trench system as initially developed and applied successfully on the Davis County Experimental Watershed in northern Utah consists of a series of zero-grade trenches spaced sufficiently close to hold 1.50 inches of rain (2). Small check dams were constructed across the trenches to segment them into about 200 compartments per mile. These dams or "equalizers" were slightly lower than the fill dike; thus water could flow from one compartment to another without overtopping the dike (fig. 7).

Figure 7.--Contour trenches constructed on the Davis County Experimental Watershed. They were designed to hold 1.50 inches of rainfall. Note spacing of about 25 feet and the small check dams being finished by hand.

Because of variable conditions encountered on mountain watersheds, no one type of trench with fixed specifications is suitable for all areas, but the basic design is fundamentally the same.

Contour trench design and application have experienced evolutionary modifications since first usage. Two types have now evolved (10): (1) the outsloping type installed on slopes up to about 30 percent, and (2) the insloping type used on slopes to 70 percent. A formula relating rainfall, trench spacing, and capacity aids in designing contour trench systems for various conditions:

$$\underset{\text{(inches)}}{\text{Rainfall}} \times \underset{\text{(percent)}}{\text{Estimated runoff}} \times \left(\frac{\text{Trench interval (ft.)}}{12}\right) = \underset{\text{(cu. ft./lineal ft.)}}{\text{Trench capacity}}$$

Trenches are located on the contour, keeping the interval rather constant (fig. 8). The most economical construction is obtained by using the largest types of crawler-tractors equipped with dozer blades. Costs per acre vary according to many circumstances, but a reasonable cost of trenching and reseeding is \$40 to \$50 per acre on moderate slopes; but on steeper slopes requiring insloping trenches, costs range from \$60 to \$100 per acre.

Pitting the soil surface is a modification of contour trenching whereby short V-shaped trenches are constructed at regular intervals. Pits vary in size depending upon the type of machinery used. Currently, in the Western United States they are about 18 inches deep and 30 inches wide, with a water-retaining capacity of about 2 cubic feet per lineal foot of pit. Under average working conditions and with a 15-foot spacing, costs should not exceed \$10 per acre (10).

Contour trenching and pitting must be augmented by seeding the treated areas. Were these mechanical structures left alone, they would soon fill with sediment and their usefulness would be negated. The practice gaining in frequency is to disk-plow those areas requiring seeding to remove highly competitive residual plants, then seed with a mixture of adapted grasses and legumes.

In California, precast concrete cribbing is often used to reestablish control in disturbed stream channels. Sections of interlocking cribbing are placed across the raw channels. They retain sediment, but pass water through their open structure. When placed in series across channels, these structures in effect modify the channel gradient by providing a series of steps in the channel. Their use has proved effective, but they are costly.

Figure 8.--A. On steep terrain, the first phase of contour trench construction is building a road the width of the blade on which the tractor operates. The vertical wall is then backsloped.

Figure 8.--B. Spill material from backsloping is pushed to the side to form the trench dike and is packed by the track of the tractor. This trench, on a 70-percent slope, is complete except for cross-dikes, which are formed by dipping the blade as the tractor backs out.

Successful stabilization of the flood-source areas on the Davis County Experimental Watershed was achieved by contour trenching that prevented overland flow. Only that precipitation intercepted directly by the channel and normal seepage flow, derived primarily from snow of the preceding winter, had to be handled by the raw channels. Under these circumstances, channel stabilization often progressed of its own accord by bank sloughing and encroachment and thickening of streambank vegetation; this stabilization eliminated the need for such costly structures as check dams, cribbing, and even debris basins.

Flood and erosion control as considered in this paper is essentially a part of watershed management. Watershed management has for its objective the maintenance of both the productive and hydrologic (or water regulatory) functions of the land. It seeks to obtain the greatest possible quantity of food, forage, wood, wildlife, and recreation from the lands and at the same time make certain that water is yielded with the greatest possible regulation and with the least possible load of sediment. These two vital functions of the land are completely interdependent.

Principles and procedures of flood and erosion control enunciated in this discussion were the fruits of analytical observation and experimentation gathered by many scientists in many places in the world. There is yet much to be done to make watershed management more effective and better understood.

MORE RESEARCH NEEDED

Three kinds of action are needed in the United States to secure more certain protection from damaging floods and sedimentation. One is stimulation of wider public understanding of the importance of forest and rangelands as watersheds, and greater public support for getting effective watershed management on those lands. Another is a speeding up and more vigorous application of tested measures for watershed protection and rehabilitation. A third is intensification and extension of both basic and applied research to fill the gaps in our knowledge about ways of preventing watershed deterioration and of restoring damaged watersheds (7).

The nature of the hydrologic, erosive, and ecologic processes involved in watershed management, as well as the factors that affect those processes, are now well known. However, much more needs to be learned about the operating limits of those processes especially in periods of extreme dryness and wetness. More needs to be learned about the safe limits to which timber, forage, and other land resources

can be used without stepping up the magnitude and frequency of flood discharges and without accelerating erosion. Further research is needed to find ways of reseeding and hastening the rebuilding of soil on many different kinds of severely eroded, steep mountain slopes. A similarly difficult problem is that of finding ways to lessen erosion and storm runoff on arid foothill and valley ranges where attempts at revegetation have thus far failed. Cheaper and more efficient adaptations of commonly used structures and machines are also needed to hasten and lessen the cost of stabilizing eroding slopes and stream channels. There is also need for many more experimental watersheds to evaluate flood and erosion control work.

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